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EFFECTS OF ADDING A NATURAL AND A MECHANICAL SOUND TO A POLYCLINIC SOUNDSCAPE ON SPATIAL KNOWLEDGE PERFORMANCE

Donya Dalir*

[1] Department of Interior Architecture, Faculty of Architecture, Yeditepe University, Istanbul/Turkey

ABSTRACT

This study explores the effects of adding natural and mechanical sounds with varying signal-to-noise ratios on spatial task performance, perceived loudness, and overall soundscape quality in a virtual polyclinic. Previous research suggests that, despite hospital sound environments generally evoking negative emotions, they may positively influence spatial tasks, depending on the characteristics and locations of sound sources. A binaural recording of the polyclinic's sound environment was analyzed in terms of its sound sources and temporal characteristics, and augmented with one natural sound (birdsong) and one mechanical sound (alarm) at different loudness levels. Thirty-five participants were randomly assigned to one of five groups: a control group (no change in the sound environment); a normalized loudness group with the addition of a natural sound; a normalized loudness group with the addition of a mechanical sound; an increased loudness group with the natural sound (3 dB louder than the background); and an increased loudness group with the alarm sound (3 dB louder than the background). The results suggested that the addition of both natural and alarm sounds at different levels enhanced participants' perception of the sound environment while decreasing perceived loudness. There was also a trend toward better spatial performance in groups with the augmented sound environment.

Keywords: *Soundscape quality, Spatial Knowledge tasks, Natural and mechanical sounds, Signal-to-noise ratio*

1. INTRODUCTION

Navigation systems typically rely on visual landmarks to guide users from one point to another. However, visual cues may not always be sufficient, particularly for elderly individuals or those with visual impairments. In certain environments, such as healthcare units, the absence of clear visual landmarks and the abundance of signage can further complicate navigation. These factors emphasize the importance of utilizing non-visual modalities as alternative sources for landmark-based wayfinding. Although vision is the dominant sense for gathering spatial information, humans possess other perceptual and cognitive abilities that can enhance the wayfinding experience [1-3].

Recent research suggests that sound can significantly influence the noticeability of visual elements [4], as changes in sound levels correspond to shifts in visual attention. Attention plays a crucial role in spatial learning [5], indicating that incorporating attention-grabbing sounds may improve spatial understanding. However, research on the role of sound in spatial knowledge, particularly in hospital settings, remains limited. This preliminary study aims to explore whether altering certain sound characteristics in the environment

***Corresponding author**: donya.dalir@yeditepe.edu.tr

can create a more positive soundscape and enhance spatial learning. By examining both the physical and perceptual dimensions of sound, the study seeks to lay the groundwork for using soundscapes as a tool to support spatial knowledge acquisition.

2. METHODS

2.1 Virtual environment

Recent research suggests that virtual systems with lower immersion, such as desktops, yield similar outcomes to higher-immersion systems in spatial cognition tasks [4]. Therefore, the outpatient polyclinic of Bilkent City Hospital was replicated virtually. This outpatient polyclinic covers a large area and features a complex layout, making it an ideal choice for the study. A video of a specific route—starting from the entrance, passing by the patient admission desks, and leading to the neurology department—was recorded in the real environment. Using Chief Architect Premier X11, a 3D simulation of the space was created. A walkthrough of the same route was developed for passive exploration using the walkthrough path tool. Consistent with prior virtual environments, the route was depicted with a plain ceiling and distinct contrast between the floor and walls. To eliminate directional cues from shadows, light sources were avoided [6]. The route included uniform, undistinguishable paths and neutral-colored walls to minimize wayfinding cues from the surroundings [7]. Figure 1 presents an image of the space.

Figure 1. A render of the virtual outpatient polyclinic

2.2. Participants

Thirty-five students and employees from Okan University, Turkey, participated in this study. None of the participants were familiar with the polyclinic. To prime the participants, they were asked to imagine being visitors in an outpatient polyclinic. Participants were randomly divided into five experimental groups, each varying in the addition of natural or mechanical sounds with different loudness levels. Each group consisted of seven people (four women and three men):

- **Group 1 (control group)**: No change in the sound environment of the polyclinic.
- **Group 2 (addition of a natural sound with normalized loudness)**: The sound environment was augmented with the addition of birdsong, which was normalized to the loudness level of the original sound environment.
- **Group 3 (addition of an alarm sound with normalized loudness)**: The sound environment was augmented with the addition of an alarm sound, normalized to the loudness level of the original sound environment.
- **Group 4 (3 dB increased loudness of the natural sound)**: The loudness of the birdsong was increased by 3 dB and added to the sound environment.
- **Group 5 (3 dB increased loudness of the alarm sound)**: The loudness of the alarm sound was increased by 3 dB and added to the sound environment.

2.2. Experimental Stimuli

To determine which segments of the sound environment to alter, the short-time frequency transform (STFT), created with MATLAB, was examined (see Figure 2). Based on this time-frequency analysis, the spectrogram was divided into several temporal segments. The third segment (75s-92s) and the fifth segment displayed lower frequency variations and less prominent features in the frequency content, recorded along the patient admission desks and the neurology department. The birdsong and alarm sounds were added to these segments of the soundscape. These segments were selected because, as seen in Figure 2, the first, second, and fourth sections of the audio content include sound variations related to the escalator, elevators, and the hubbub of people in the entrance to the neurology department. Based on the results of a previous study [8], these variations may aid users in spatial knowledge tasks, so modifications were not made in these segments.

The sounds added to the selected segments were birdsong and alarm sound, as depicted in Figure 3 and 4.

Adobe Audition software was used to create the audio for Groups 2, 3, 4, and 5. For Groups 2 and 3 (normalized loudness), the loudness of the alarm sound and birdsong were matched to the existing sound environment of the outpatient polyclinic before being added to the original sound environment. For Groups 4 and 5, the loudness of the birdsong and alarm sound was increased by 3 dB before being added to the original sound environment.

The auditory recordings for Groups 2 and 3 were added to the video using the Walkthrough path tool in Cyberlink PowerDirector editing software. Clapping synchronized the video and audio. Models were animated with a wide-angle lens to offer a 65-degree field of view, enhancing immersion. The eye level was set at 1.60 meters, and the walking pace remained constant at 1.1 m/s [9-11]. The video lasted 220 seconds. The route spanned 154 meters with eight directional changes (three left turns and five right turns), identical across conditions. Visuals were presented via a 17-inch Asus PC (2.59 GHz, 16 GB RAM, nVidia GeForce GTX 960), positioned on a desk, with participants sitting approximately 50 cm away. Testing occurred individually in a closed-door, window-blocked experimental room. Sound information was delivered via headphones (ROG Strix Fusion 300 7.1) connected to the computer.

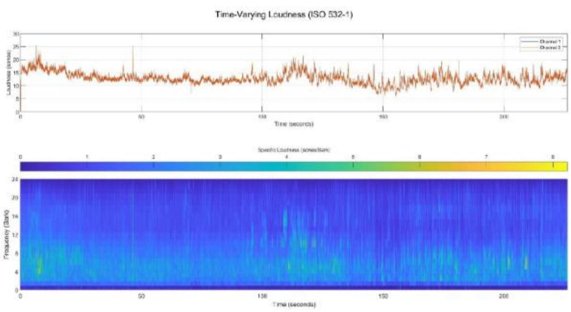

Figure 2. Time-varying loudness figure of the original sound recording

Figure 3. Representation of the birdsong

Figure 4. Representation of the alarm sound

2.3. Procedure

Before the experiment, participants' hearing was tested using the Widex online hearing test. All participants had normal hearing. Afterward, they were asked to provide demographic information about themselves. Following the demographic survey, participants listened to the sound recording corresponding to their assigned group, using headphones and without visuals. They were then asked to rate the sound on a 5-point Likert scale, evaluating the sound environment (1 = very bad, 5 = very good), its appropriateness for an outpatient polyclinic (1 = not at all, 5 = perfect), and the perceived loudness of the sound environment (1 = very quiet, 5 = very loud).

Additionally, participants were asked to rate the sound environment using the Mehrabian–Russell model, which uses the Pleasure, Arousal, and Dominance (PAD) scale [12]. In addition to the adjective pairs in the M-R model, we included additional adjective pairs from previous soundscape studies: unpleasant-pleasant, gloomy-fun, and noisy-quiet [13-14]. After analyzing the questionnaire results, five adjective pairs—sleepy–wide awake, sluggish-wild, dominant-submissive, in control-cared for, and autonomous-guided—were removed. Many participants did not fully understand these adjective pairs and had difficulty relating them to the sound environment. To avoid potential bias, these five pairs were excluded from the analysis.

Following the listening task, participants were instructed to view the prepared video corresponding to their assigned experimental group. To reduce potential biases in responses and attention, participants were kept unaware of the subsequent tasks. The video began at the outpatient polyclinic entrance, traveled through the patient admission desks and elevators, and ultimately reached the neurology department. Spatial layout details were withheld from participants during the learning phase.

2.4. Spatial knowledge tasks

After watching the video, all groups engaged in three spatial memory tasks based on the Landmark-Route-Survey model representation. Landmark knowledge was assessed through a landmark placement task (Task 1), route knowledge was evaluated via a scene sorting task (Task 2), and survey knowledge was measured using a pointing task (Task 3). Upon completion of these tasks, participants filled out the Santa Barbara Sense-of-Direction scale questionnaire, which consists of 15 questions, to self-report their spatial abilities [15].

2.5. Data Analysis

The data were analyzed using the Statistical Package for the Social Sciences (SPSS 25.0, IBM, USA). Internal reliability for all tasks was deemed satisfactory, with Cronbach's α ranging from 0.70 to 0.88. Levene's test indicated homogeneity of variance across all tasks, allowing for the use of parametric tests. A one-way ANOVA was used to analyze differences across all tasks, and post-hoc pairwise comparisons between groups were conducted using the Scheffé test.

3. Results

3.1. Listening test results across the groups

The mean score of each semantic pair was calculated to analyze whether there were differences in the perceptual attributes of the sound environment across the groups. Results of a Chi-square test indicated significant differences in the following adjective pairs: unpleasant-pleasant ($X^2(16) = 32.798$, $p < 0.05$), melancholic-contented ($X^2(16) = 29.19$, $p < 0.05$), dissatisfied-satisfied ($X^2(16) = 23.712$, $p < 0.05$), and uninteresting-interesting ($X^2(16) = 29.273$, $p < 0.05$). Figures 5 and 6 present the bar graph and radar graph of the semantic differential scale. As seen in the radar graph, there are overlaps among specific adjectives in some of the groups.

Overall, the addition of both mechanical and natural sounds seemed to enhance the general perception of the soundscape. Group 4, which included the addition of birdsong with a 3 dB increase, was rated positively across most adjectives. Although there was no significant difference in the "quiet-noisy" adjective pairs, Group 5, which included the addition of an alarm sound with a 3 dB increase, was rated as the noisiest, while Group 4 was rated as the quietest. Given that the loudness level in Group 4 was higher than in Groups 1, 2, and 3, this result may be significant. Similar patterns were observed in Group 2 as well.

In terms of the addition of the alarm sound, the major overlaps in the perception of the adjective pairs were observed between Group 1 and Group 3. However, Group 5 was rated more positively across most adjective pairs compared to Group 1, although Group 5 was also rated as the noisiest soundscape.

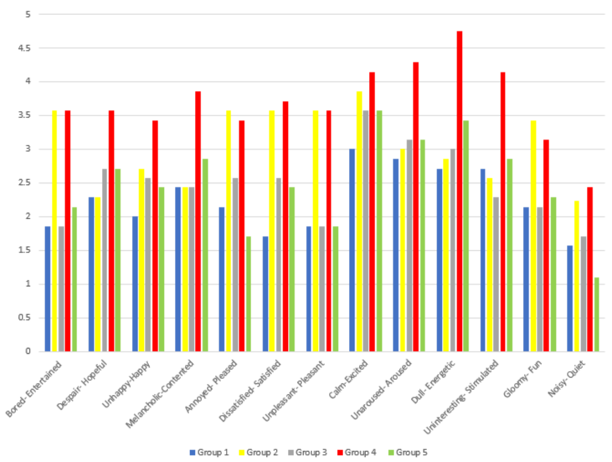

Figure 5. Bar graph of the mean scores of perceptual attributes of the sound environment

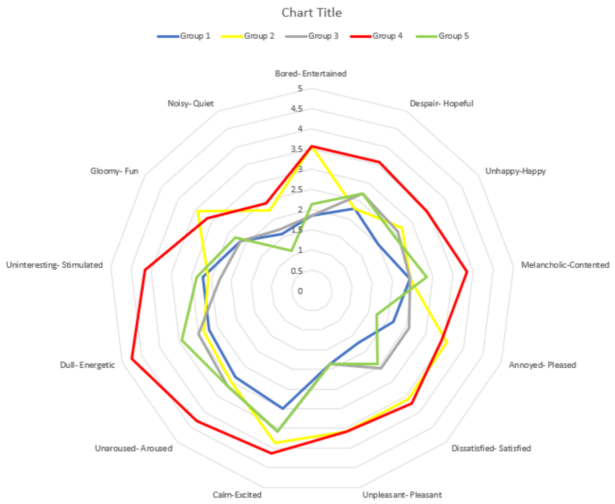

Figure 6. Radar graph of mean scores of perceptual attributes of the sound environment

3.2. Spatial knowledge performances in each task

The Santa Barbara Sense of Direction questionnaire results indicated no significant differences in the self-reported spatial abilities of the participants: $F(2, 21) = 1.649$, $p = 0.216$, $\eta^2 = 0.136$. Therefore, any observed differences in performance tasks can be attributed to the effect of the experimental group.

Task 1 (Landmark placement on a sketch) analysis: In this task, participants were asked to place the escalator, staircases, elevators, and patient administration desks as accurately as possible on a blank plan. The answers were scanned and uploaded to the Gardony Map Drawing Analyzer. The canonical organization's square root was compared between the groups for scoring purposes. The results indicated a significant difference in performance: $F(4, 30) = 3.533$, $p < 0.05$, $\eta^2 = 0.805$. A Scheffé Post Hoc Test was applied to compare performance in a pairwise fashion. There was a significant difference between Group 1 and Group 5 ($p = 0.029$); however, no significant differences were found between the other groups.

Although there were no significant differences between the other groups, the bar graph shows that Group 5 (mean score = 0.89271) and Group 4 (mean score = 0.76571) had the highest performance, while Group 1 had the lowest (mean score = 0.41441).

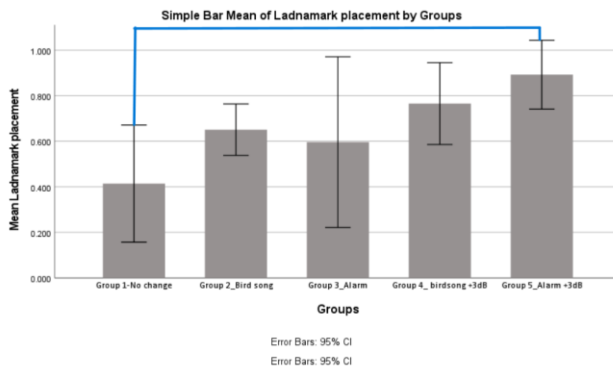

Figure 7. Mean scores in the landmark placement across the five experimental groups. Asterisks indicate significant differences at $p < .05$

Task 2 (Scene sorting task) analysis: In this task, participants were presented with eight pictures taken along the route and were asked to sort them chronologically. Comparisons of the percentages of correctly ordered pictures indicated a significant effect of the experimental group on performance: $F(4, 30) = 6.837$, $p < 0.05$, $\eta^2 = 0.984$. The Scheffé post hoc test revealed differences between Group 1 and Group 3 ($p < 0.05$), Group 1 and Group 5 ($p < 0.05$), Group 1 and Group 4 ($p < 0.05$), and a trend between Group 1 and Group 2 ($p = 0.054$). The bar graph shows that participants in Group 3 (mean score = 88.5) performed better than those in Group 2 (mean score = 62.5) and Group 1 (mean score = 35.938). Figure 8 illustrates the data distribution in Task 2 across the groups.

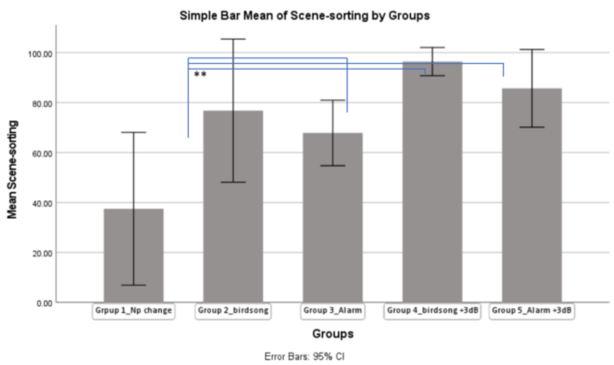

Figure 8. Mean scores in the scene sorting task (Task 2) across the five experimental groups. Asterisks indicate significant differences at $p < .05$

Task 3 (Pointing task) analysis: In this task, participants were asked to imagine standing at a given landmark, facing another, and pointing to a third landmark, similar to previous studies [25]. For scoring purposes, the average deviation between the pointed direction and the correct direction across all four questions was compared.

The results indicated no significant effect of the experimental group on performance: $F(4, 30) = 1.292$, $p = 0.295$, $\eta^2 = 0.353$. Although no significant differences were found between the groups, the average deviation from the correct direction was the lowest for Groups 2 and 4, with 35.16° and 33.749°, respectively. Group 1 and Group 3 had the highest deviations, with 70.536° and 72.5°, respectively.

Overall, the results indicated a positive impact of adding both natural and mechanical sounds on spatial knowledge acquisition. A significant difference was found in the landmark placement task and scene sorting task between Group 1 and Group 3. Although no significant difference was detected in the pointing task, a comparison of the mean values shows improved task performance in Groups 2 and 3. With a larger sample size, the differences in performance may become more significant.

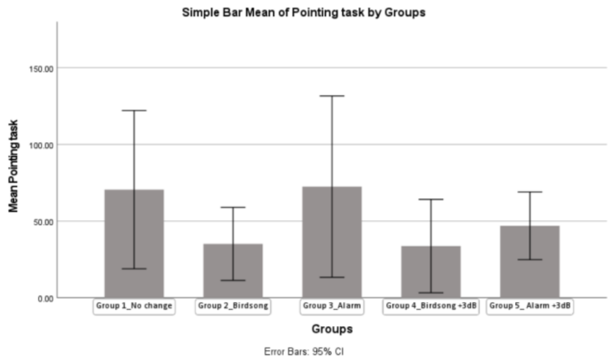

Figure 9. Mean scores in the scene sorting task (Task 3) across the five experimental groups.

4. Conclusions

Exploration of visual attributes in wayfinding studies has highlighted the importance of brightness. Research suggests that brightly lit corridors are more attractive than wider ones [16]. Additionally, warm colors with high brightness levels are better remembered, while cool colors with high brightness help with spatial orientation [17]. Brightness is also associated with positive emotions and is generally preferred. Given the correlation between sound loudness and visual brightness, it was anticipated that increasing the loudness of a sound would enhance its perception.

The results indicated that increasing sound loudness led to slight improvements in perception across most adjective pairs. Some participants noted that louder mechanical and natural sounds helped balance the overall sound environment in hospitals, reducing annoyance. However, participants' prior knowledge that they were listening to a recording of an outpatient polyclinic may have biased their perception, potentially leading to more negative responses. To minimize such bias in future studies, providing contextual information beforehand should be avoided.

Regarding spatial knowledge tasks, significant variances were only observed in the landmark placement and scene sorting tasks between certain groups, though the results show promise. A larger sample size would likely clarify the impact of loudness on spatial knowledge tasks and the perception of space, thus laying the groundwork for using sound as soundmarks to facilitate wayfinding.

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